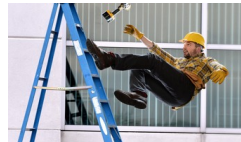


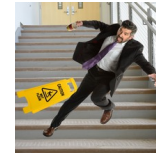
Ionizing Radiation Risk

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Hazard Ranking Activity



Terminology

- ▶ Latent cancer – a cancer condition that is present but not active or causing symptoms
- ▶ LNT – Linear No-threshold (radiation dose-response model)
- ▶ BEIR V – Biological Effects of Ionizing Radiation Committee V
- ▶ ICRP – International Commission on Radiological Protection
- ▶ UNSCEAR – United Nations Scientific Committee on the Effects of Atomic Radiation

Risk Issues are
Emotional
Solutions are Technical
Decisions are Political

Risk Maxims

- ▶ Risk issues are emotional
 - More often than not, risks (or hazards) have more to do with perception than reality
 - Human behavior primarily driven by emotion, not by facts
- ▶ When hazards not avoidable, risk mitigation measures generally technical in nature
- ▶ Risk solutions and decisions rarely without opposition
 - Alternative solutions often negotiated before final decision rendered
 - Economics and safety not always paramount in decision-making

Risk Definition

$$\text{Risk} = \frac{\text{No. of injuries or deaths}}{\text{No. of people exposed to hazard}}$$

Theoretical risk calculation based on inference, extrapolation from clinical studies, or epidemiology studies

Real **measured risk** based on observation

Emotional Aspects of Risk Perception

- Acceptable

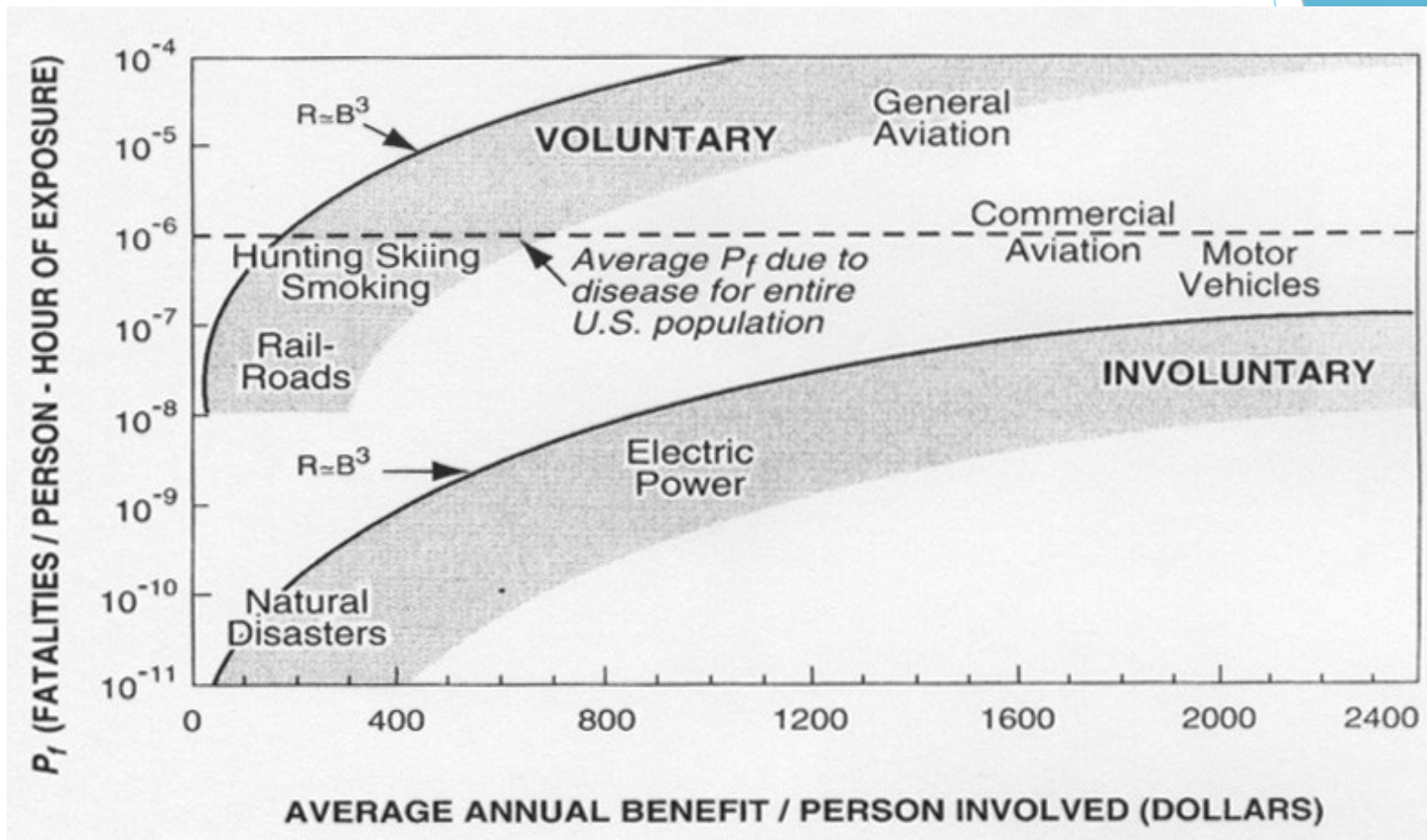
- Voluntary
- Individual control
- Clear benefits
- Trustworthy sources
- Ethically neutral
- Natural
- Familiar
- No historical associations
- Less dread
- Visible
- Immediate effect
- Known, understood
- Little media attention

- Unacceptable

- Involuntary
- Others control
- Unclear benefits
- Untrustworthy sources
- Ethically objectionable
- Artificial
- Exotic
- Memorable associations
- High dread
- Undetectable
- Delayed effect
- Uncertainty, variability
- High media attention

Many Ways to Compare Risks

Representative Acceptance Domains for Voluntary and Involuntary Risks



Risk of 1 in a Million Chance of Dying

- ▶ Smoking 1.4 cigarettes (lung cancer)
- ▶ Eating 40 tablespoons of peanut butter (aflatoxin)
- ▶ Spending 2 days in New York City (air pollution)
- ▶ Driving 40 miles in a car (accident)
- ▶ Flying 2,500 miles in a jet (accident)
- ▶ Canoeing for 6 minutes (drowning)
- ▶ Receiving 10 mrem (0.1 mSv) of radiation

(cancer)
Adapted from DOE Radiation Worker Training, based on work by B.L. Cohen, Sc.D.

Estimated Loss of Life Expectancy from Industrial/Health Hazards*

General Risk/Attitude Correlation for *Involuntary* Risk of Death*

Involuntary Risk (deaths per person per year)	General Attitude
10^{-2}	Natural death reference
10^{-3}	Unacceptable; activities having this involuntary risk necessitate remedial actions
10^{-4}	Acceptable; effort and money spent to reduce risk to this level
10^{-5}	Only mild inconvenience acceptable to avoid this level of risk
10^{-6}	Considered an “act of God”

- Starr, C., “Social Benefit vs. Technological Risk,” *Science*, Vol. 165, September 1969, pp. 1232-1238

Ionizing Radiation Hazard

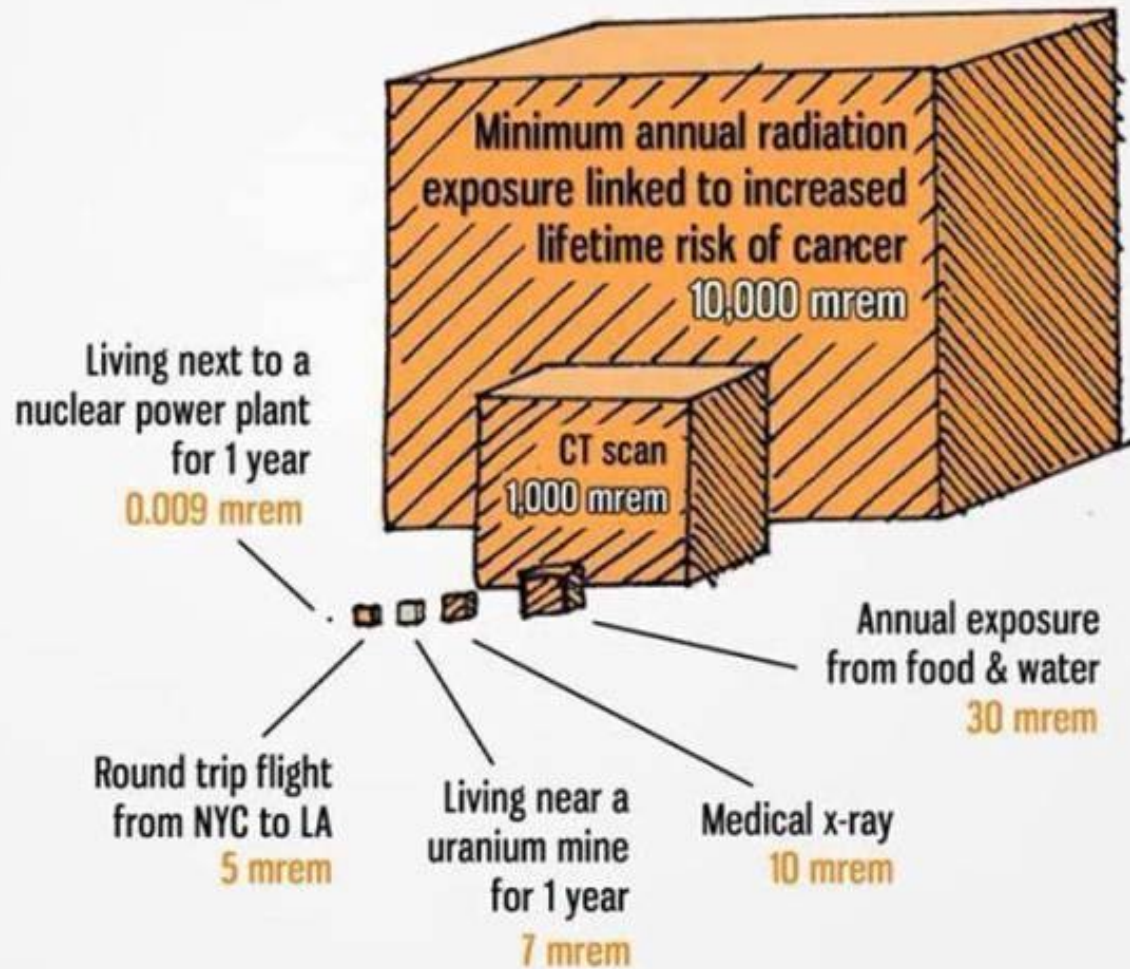
Radiation Hazard

- ▶ Radioactive material is potentially hazardous
- ▶ Extent of hazard depends on
 - Quantity (Ci, mCi, μ Ci, nCi or pCi)
 - Type of radiation (alpha, beta, gamma, neutrons)
 - Energy of radiation (MeV, KeV, eV)
 - Form (sealed source, electroplated, unconfined)
 - Phase (solid, liquid, particulate or gas)
 - Shielding between receptor and source
 - Distance to receptor from source
 - Exposure time
 - Type of exposure (external, inhaled, or ingested)
- ▶ Dose a function of all of the above
- ▶ Dose units: for gamma-rays and x-rays $1 \text{ Gy} = 1 \text{ Sv} = 100 \text{ Rem}$

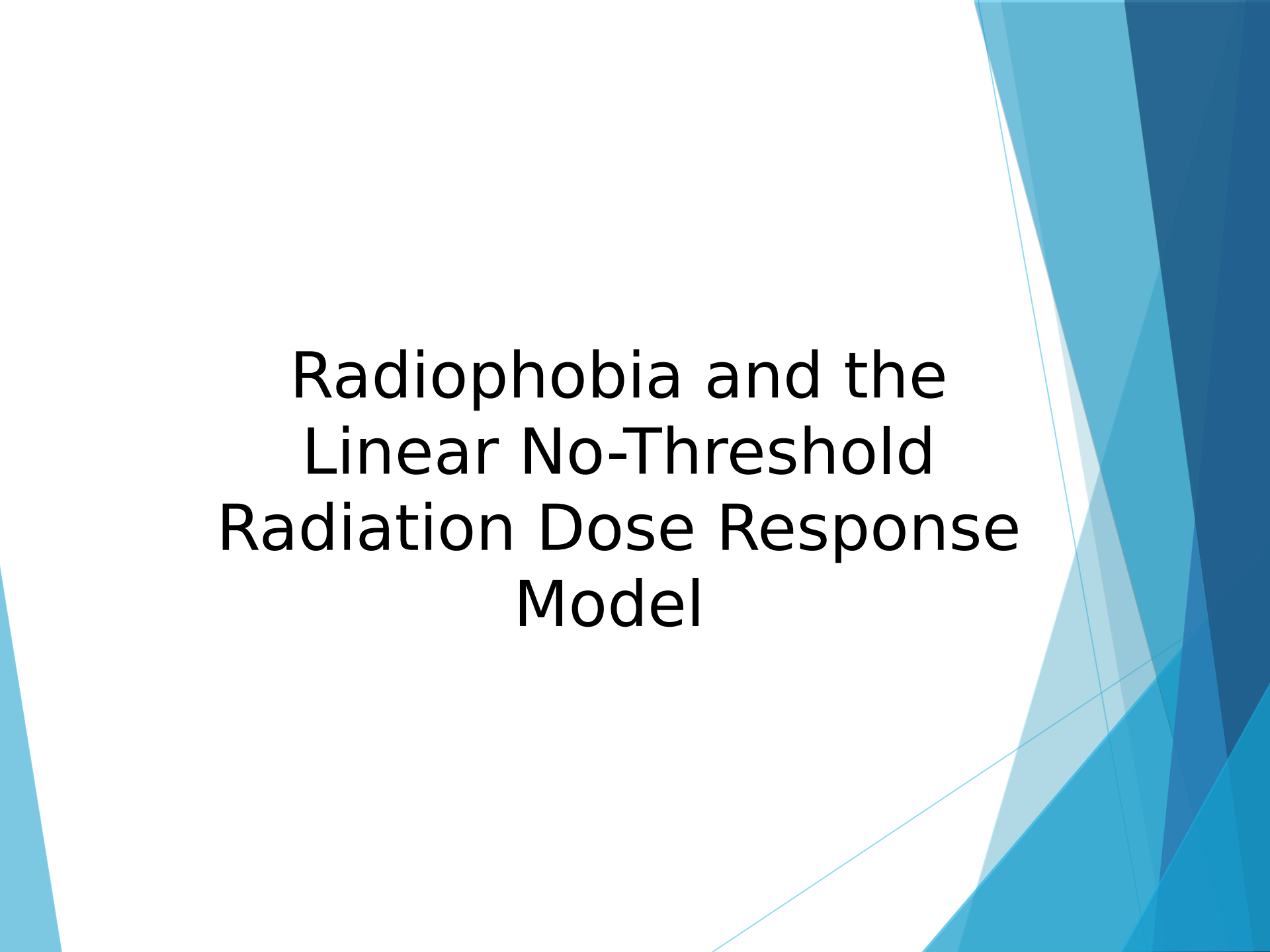
Relative Radiation Hazards

- ▶ Sun – familiar hazard
 - natural ionizing radiation hazard – doesn't evoke great fear
 - causes 1.3 million skin cancer cases in U.S. each year¹
 - causes 7,800 melanoma deaths in U.S. each year¹
- ▶ Nuclear radiation – unfamiliar hazard
 - “man-made” radiation incorrectly perceived as different from natural radiation
 - weaker carcinogen than most people think
 - caused only about 500 cancer cases among 90,000 survivors of atomic weapons in Hiroshima and Nagasaki¹

RADIATION IN PERSPECTIVE



www.IDigUMining.com

The background features abstract, overlapping geometric shapes in various shades of blue, primarily on the right side of the slide, creating a modern, angular design.

Radiophobia and the Linear No-Threshold Radiation Dose Response Model

Radiophobia Historical Background

▶ 1950

- Albert Einstein estimated that *'radioactive poisoning of the atmosphere (by H-bombs) and hence annihilation of any life on earth, has been brought within the range of technical possibilities'*
 - Hans Bethe warned on television that H-bomb clouds *'could annihilate life on earth'*
- ▶ Similar statements repeated in publications, books, and movies of 1950s (On the Beach, Failsafe, Dr. Strangelove)

Radiophobia Historical Background (cont.)

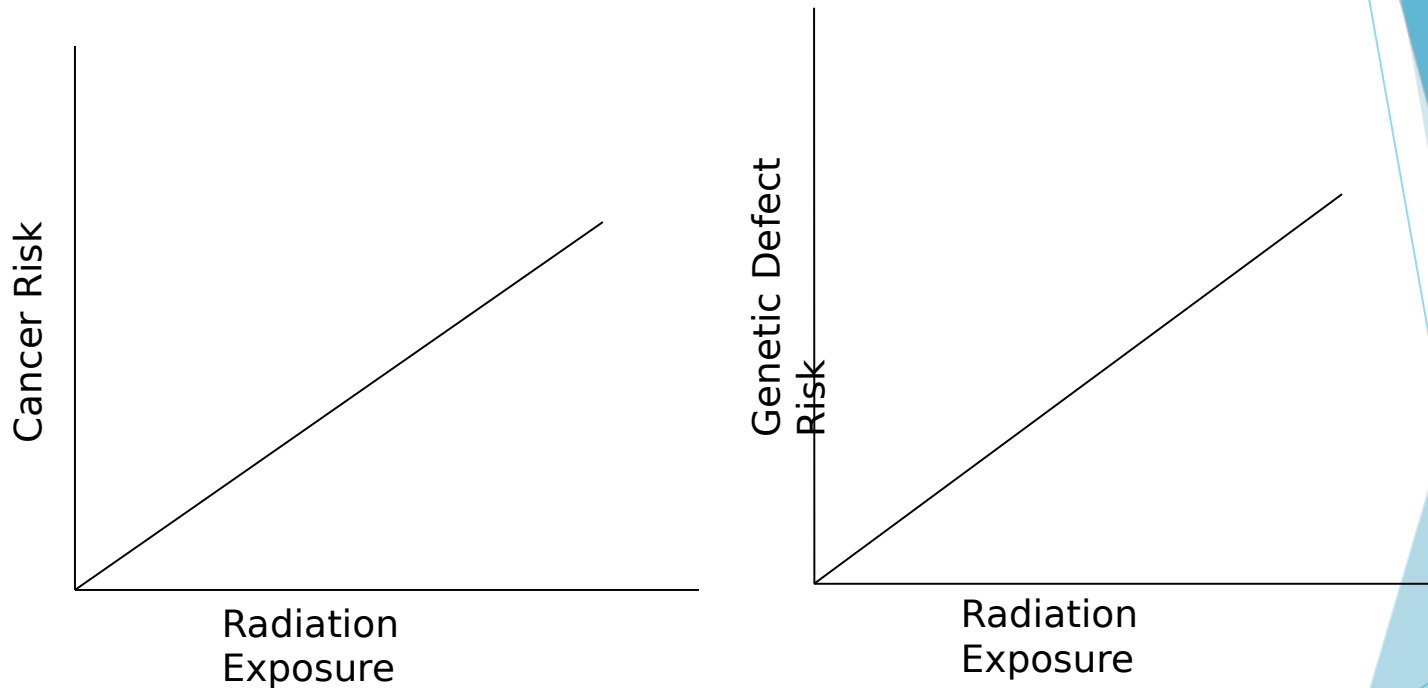
▶ 1958

- Linus Pauling estimated genetic effects from atmospheric nuclear weapon testing: *'I state that nuclear tests would seriously damage over 20 million unborn children, including those caused to have gross physical or mental defect, and also the still births and embryonic, neonatal and childhood death.'*
- ▶ Detrimental health effects associated with **high-dose** x-ray, gamma-ray, and beta-ray irradiations, were used to extrapolate to zero dose and became basis for assumption that radiation-induced cancer and mutation risk increases linearly with dose without any threshold

Radiophobia Historical Background (cont.)

- ▶ When nuclear arms race between US and Russia began after WWII, well-meaning scientists created radiation scare to stop atomic bomb testing (radioactive fallout)
- ▶ Linear no-threshold (LNT) dose response model created in 1956 to link low-dose ionizing radiation to risk of cancer death

Linear No-Threshold (LNT) Dose-Response Model



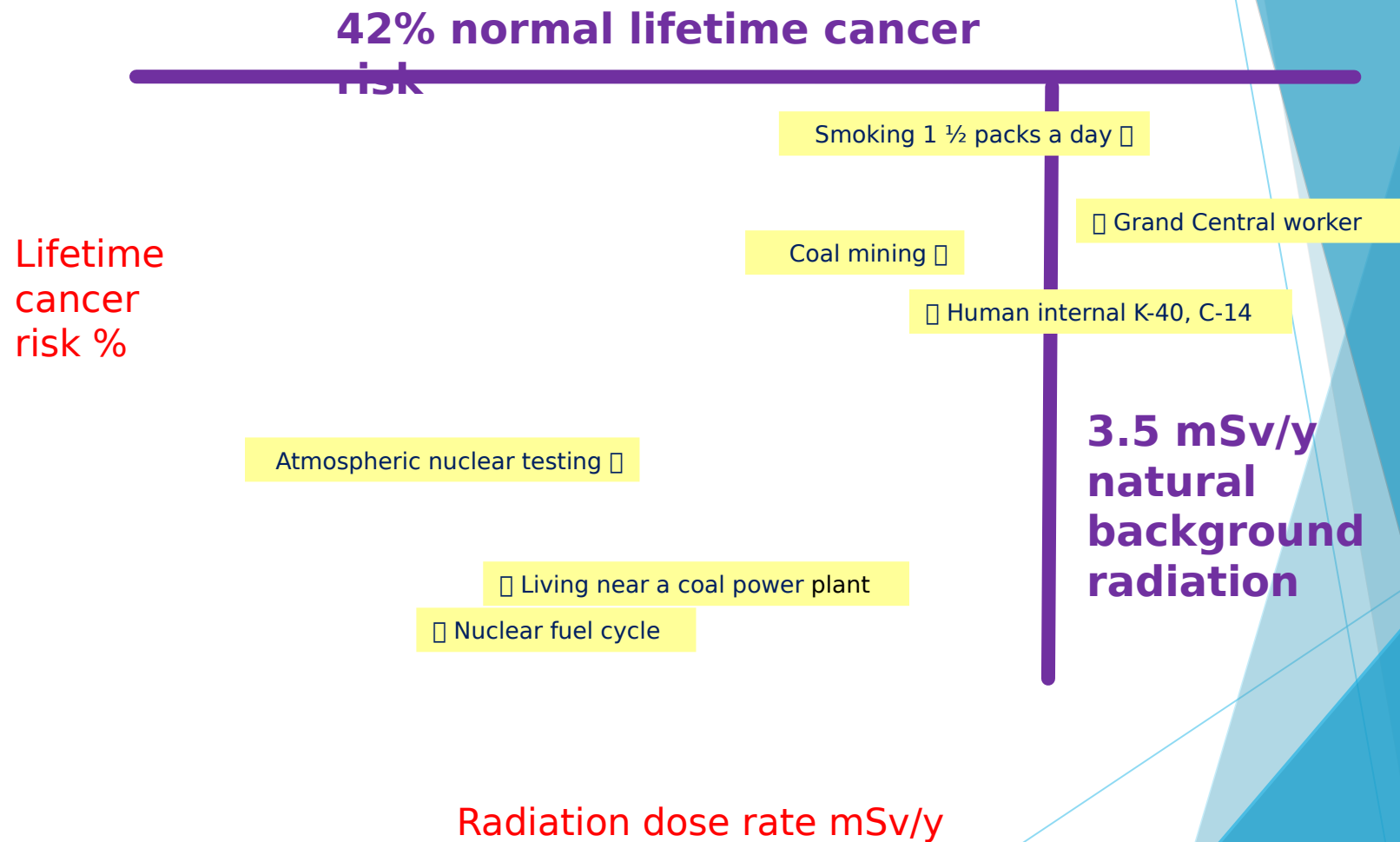
Extrapolation is from effects of very high (acute) doses received by atomic bomb survivors.

LNT Cancer Risk Assumptions

- ▶ Non-cancer specific
- ▶ Non-organ dose specific
- ▶ Exposure is cumulative exposure to whole body
- ▶ Collective dose risk, ICRP 60 (1991)¹³
 - 0.0004 risk of fatal cancer per rem (0.04 per Sv) = 1 in 2,500 chance of fatal cancer per rem of exposure (1 in 25 per Sv) for occupational workers*
 - 0.0005 risk per rem (0.05 per Sv) = 1 in 2,000 chance of fatal cancer per rem of exposure (1 in 20 per Sv) for general population*

* These values take into account uncertainties in probability estimates of fatal cancer used in radiation protection and assume several factors derived from scientific and epidemiological studies for lifespan of the population, quality of the radiation, total body exposure, and **linear response at low doses**.

LNT Predicts Cancer Risk Based on Cumulative Low-Dose Exposures



Low-level Radiation Effects

Invisible or Not There?

- ▶ Studies of populations *chronically* exposed to elevated natural background radiation (low-level radiation) show no consistent or conclusive evidence of associated increases in cancer risk²
- ▶ Atomic bomb survivors who received acute doses less than 0.5 Sv (50 rem) showed no statistically significant increase in genetically related diseases²

Fallacy of Cumulative Dose Assumption

- ▶ Rotating x-ray beam focused on cancer tissue delivers up to 80,000 mSv of radiation
- ▶ To minimize small risk of causing cancer in nearby tissue, total radiation dose divided into fractions
- ▶ Delivery of fractional doses over non-consecutive days gives healthy tissue time to recover between doses (adaptive

protection)
If LNT were true, fractionated radiation therapy (3 million therapies per year) would not work



Collective Dose Concept

LNT dose-response model, accepted in 1959 by International Commission on Radiological Protection (ICRP) as philosophical basis for radiological protection, birthed concept of “collective dose”

Collective dose – expression for aggregate radiation dose incurred by a population, defined as product of number of individuals exposed to radiation source and average radiation dose

Illustration of Collective Dose Fallacy

Illustration: applying collective dose concept to non-radiation hazard

- ▶ Assume 100 mg of arsenic, taken all at once, is lethal dose for adults (actual lethal dose is 120-200 mg, and biological half-life is ≈ 4 days)
- ▶ Lethal dose then characterized as 100 person-mg (on average, adult human body contains about 3 mg, or 3,000 μg , of arsenic)
- ▶ Assume 1 μg given to each of 100,000 adults (population dose is then 100 person-mg)
- ▶ If lethal dose is 100 person-mg, can anyone die from single microgram dose of arsenic?

Collective Dose Fallacy (cont.)

Illustration (cont.)

- ▶ LNT dose-response model asserts if probability of death is 100% for ingestion of 100,000 μg of arsenic, then probability of death is 90% for ingestion of 90,000 μg , 50% for 50,000 μg , and 0.001% for 1 μg
- ▶ Although risk is extremely small, LNT risk-based theory predicts that if 100,000 people each ingest 1 μg of arsenic, one will find a way to die (by adding 1 μg to the 3,000 μg already in his/her body)

Collective Dose Fallacy (cont.)

Calculating radiation risk from home smoke detectors using collective dose and LNT model²

- ▶ Am-241 source results in average household personnel exposure of 0.008 mrem (8×10^{-5} mSv) per year from 59.5 keV gamma-ray accompanying alpha decay (Ref. U.S. Nuclear Regulatory Commission) **Note that this is a chronic, not acute, dose.**
- ▶ Assume 0.008 mrem annual exposure of 200 million people (80% of U.S. population)
- ▶ Collective dose concept asserts annual latent fatal cancer risk is 1,600 person-rem

Collective Dose Fallacy (cont.)

Calculating radiation risk from home smoke detectors (cont.)

- ▶ Assume cancer mortality “risk factor” of 5 in 10,000 per rem³ (**0.05% per rem is conservatively high for chronic exposure**)
- ▶ Risk is additional 0.8 fatal cancers among exposed population of 200 million people
- ▶ No proof that average annual exposure of 0.008 mrem to an individual from home smoke detector produces any harmful effects (average annual dose to individuals in U.S. is 360 mrem from all sources), but also no way of proving it doesn't if cumulative dose assumed to be valid

Collective Dose Fallacy (cont.)

- ▶ Collective dose can achieve large mortality risk factor by multiplying small individual radiation doses by large numbers of potentially exposed individuals
- ▶ 0.0005 risk per rem = 1 fatality per 2,000 person-rem as shown below

Fatalities	Dose (mrem)	Persons Exposed	Person-rem
1	1,000	2,000	2,000
1	100	20,000	2,000
1	10	200,000	2,000
1	1	2,000,000	2,000
1	0.1	20,000,000	2,000
1	0.01	200,000,000	2,000

Refutation of Collective Dose Concept

In 2007 the ICRP modified its position on collective dose, stating that “collective effective dose is an instrument for optimization, for comparing radiological technologies and protection procedures. Collective effective dose is not intended as a tool for epidemiological studies, and it is inappropriate to use it in risk projections. Specifically, the computation of cancer deaths based on collective effective doses involving trivial exposures to large populations is not reasonable and should be avoided.”

Ref. ICRP Publication 103, Recommendations of the International Commission on Radiological Protection, 2007

Refutation of Collective Dose Concept (cont.)

Position statement of Health Physics Society*

- ▶ A large dose to a small number of people is not equivalent to a small dose to many people, even if the collective doses are identical.
- ▶ For populations estimated to receive a lifetime dose less than 100 mSv [10 rem] above background, collective dose is highly speculative and an uncertain measure of risk and should not be used for estimating population health risks.

* *Radiation Risk in Perspective*, Position Statement of the Health Physics Society;
adopted January 1996, Revised July 2010

Refutation of Collective Dose Concept (cont.)

We should change our approach to radiation exposure and eliminate the LNT and collective dose, which have perpetuated the use of a fraudulent indicator that bears no relation to the onset or likelihood of health effects or cancer.

A. David Rossin, past President of the American Nuclear Society

LNT Model Perpetuates Radiation Phobia

Despite failure of adverse health consequences to materialize from low dose radiation, linear no-threshold (LNT) risk model persists to this day, helping to perpetuate **low-dose** radiation phobia

If LNT were correct, we would have been extinct a long time ago.

Chary Rangacharyulu

Deception of Linear No-Threshold Dose-Response Model

The Deception of LNT

- ▶ Calabrese, E.J., *An abuse of risk assessment: how regulatory agencies improperly adopted LNT for cancer risk assessment*, Arch. Toxicol. DOI 10.1007/s00204-015-1454-4, 18 January 2015
- ▶ Calabrese, E.J., *Cancer risk assessment foundation unraveling: New historical evidence reveals that the US National Academy of Sciences (US NAS), Biological Effects of Atomic Radiation (BEAR) Committee Genetics Panel falsified the research record to promote acceptance of the LNT*, Arch. Toxicol. DOI 10.1007/s00204-015-1455-3, 20

The Deception of LNT (cont.)

Precautionary Principle* most often used as basis for why LNT dose-response model should remain standard for radiation risk assessment

* Precautionary Principle – the introduction of any product
or process whose ultimate effects are uncertain or
disputed should be resisted

LNT Deception Consequences

- ▶ Many complex nuclear energy facility regulations to prevent very unlikely events that could release small amounts of radioactive material have hugely increased costs of facility construction and operation
- ▶ The As Low As Reasonably Achievable (ALARA) protocol also unnecessarily increased operating costs of nuclear energy facilities

ALARA Consequences

- ▶ Potential low-dose therapies for inflammatory diseases (e.g., pneumonia), autoimmune, neurodegenerative, and other diseases shunned by some in medical industry
 - Option of convenient, affordable low-dose radiation treatments not always available to patients
- ▶ Reluctance of some doctors to use nuclear medicine diagnostic imaging procedures

ALARA Consequences (cont.)

- ▶ Potential for inadequate diagnostic images necessitating multiple diagnostic procedures
- ▶ Large expenditures of money to reduce already low radiation exposures with no discernable health benefit
- ▶ Public remains fearful of harmless radiation exposures

Unwarranted Expenditures Due to LNT Deception

- ▶ Annual public radiation doses from abandoned U.S. uranium mill tailings sites (UMTRA* Project) assessed using collective dose concept
- ▶ Number of cancer deaths at each site over next 100 years predicted from LNT model using collective dose assessment data
- ▶ Overall cost-effectiveness \$1.1 million per (predicted) cancer death averted
- ▶ Many site cleanup costs both unwarranted and excessive

* Uranium Mill Tailings Remedial
Action

Table 1. Estimated cost and cancer deaths prevented by the UMTRA project based on FY98 federal UMTRA budget.

Site	Excess cancer deaths prevented by remedial action	Predicted nonradiological fatalities	Actual nonradiological fatalities	Total deaths prevented	Total project cost \$millions	Cost/death prevented \$millions ^c
Grand Junction, CO	589	0.35	1 ^b	588	256.3	0.44
Salt Lake City, UT	313	0.14	0	313	75.0	0.24
Rifle, CO	40	0.36	0	40	94.9	2.4
Durango, CO	22	0.025	0	22	63.1	2.8
Canonsburg, PA	15.0	0	0	15.0	35.8	2.4
Gunnison, CO	6.5	0.052	0	6.5	63.2	9.7
Riverton, WY	5.6	0.55	0	5.6	45.6	8.1
Falls City, TX	2.3	0.040	0	2.3	56.7	25
Shiprock, NM	2.0	0	0	2.0	22.9	11
Tuba City, AZ	1.9	0.070	0	1.9	34.9	18
Mexican Hat, UT	1.3	0.029	0	1.3	53.2	41
Naturita, CO	0.91	0.072	0	0.91	59.8	66
Lakeview, OR	0.27	0.022	0	0.27	32.6	120
Ambrosia Lake, NM	0.086	0.20	0	0.086	39.0	450
Monument Valley, AZ	0.016	0.012	0	0.016	23.3	1,500
Lowman, ID	0.013	0.0070	0	0.013	14.9	1,100
Green River, UT	0.007	0.024	0	0.007	21.5	3,100
Slick Rock, CO	0.003	0.085	0	0.003	53.1	18,000
Maybell, CO	0.003	0.063	0	0.003	39.1	13,000
Spook, WY	0.002	0.019	0	0.002	10.3	5,200
Site totals	1,000	2.22	1	999	1,105.2	1.1
Vicinity properties	290 ^a	0.019	0	290	345.2	1.2
Grand totals	1,290	2.24	1	1,289	1,450.4	1.1

^a Calculated according to the formulas below by taking the total excess health effects estimated from continued exposure under conditions of no remedial action occurring over 100-y period of time minus the total excess health effects estimated during and after the proposed remedial action for 100-y, resulting in the net number of radiological health effects prevented by the remedial action.

Lack of Low-Dose Radiation Evidence to Support LNT

“No reproducible evidence exists of harmful effects from increases in background radiation three to ten times the usual levels. There is no increase in leukemia or other cancers among American participants in nuclear testing, no increase in leukemia or thyroid cancer among medical patients receiving Iodine-131 for diagnosis or treatment of hyperthyroidism, and no increase in lung cancer among non-smokers exposed to increased radon in the home.”

Radiation Phobia

- ▶ LNT model, collective dose concept, and ALARA protocol continue to perpetuate low-dose radiation phobia
- ▶ Reason that low-dose ionizing radiation studies cannot be [absolutely] conclusive is that risk, if any exists at low radiation levels, too small to be seen in presence of other risks of life*

* Report NT-14-3, *Occupational Radiation Exposure from Naval Reactors'*

Department of Energy Facilities, May 2014

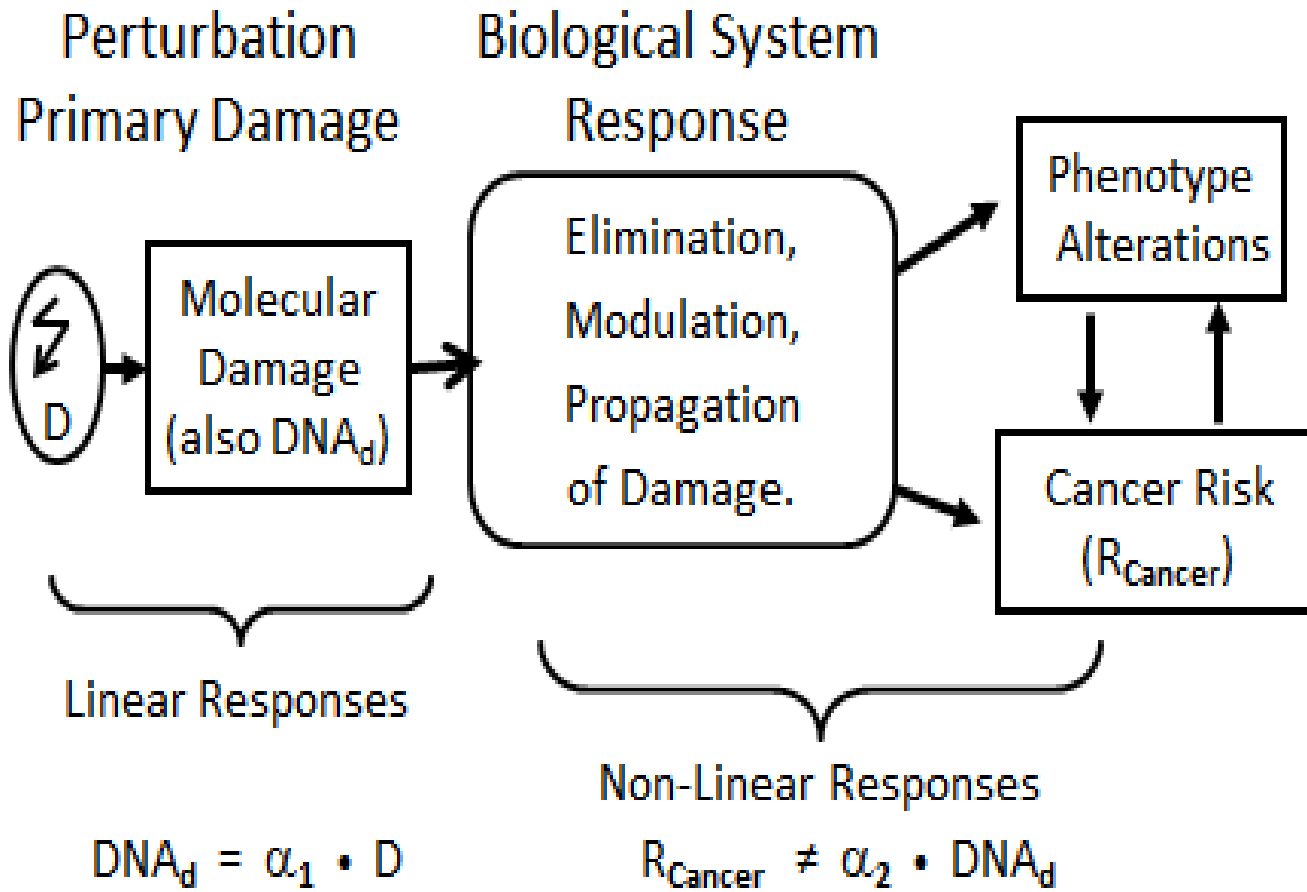
Fallacy of LNT YouTube Video

The link below provides an excellent 30-minute presentation on the fallacy of the linear no-threshold dose-response model currently used for regulating ionizing radiation exposures (as well as a refutation of the home radon hoax). If you ever had a concern about ionizing radiation exposure from home radon or nuclear medicine diagnostic procedures, you need to watch this video.

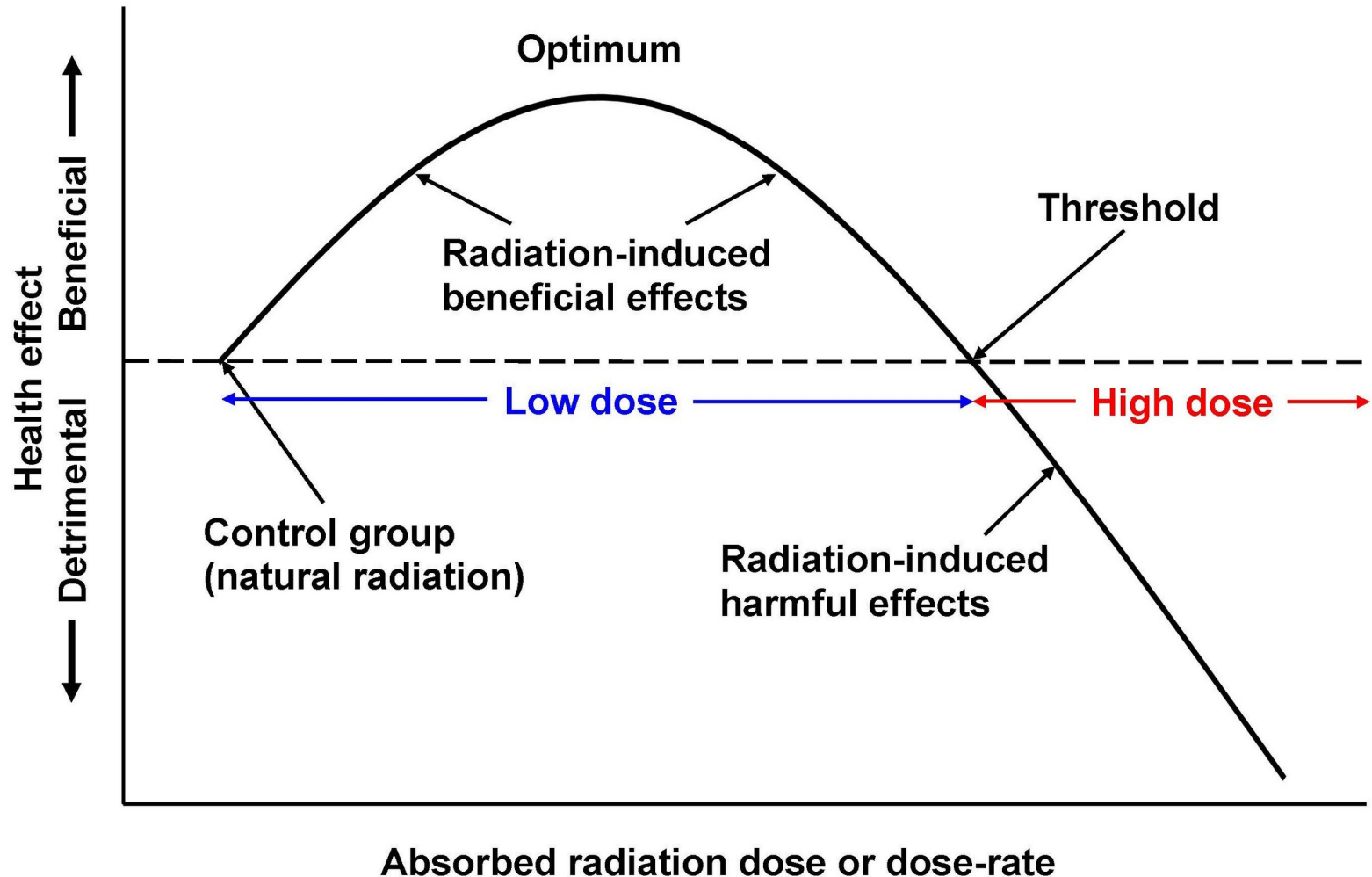
<https://www.youtube.com/watch?v=gzdLdNRaPKc>

A Realistic Radiation Dose-Response Model

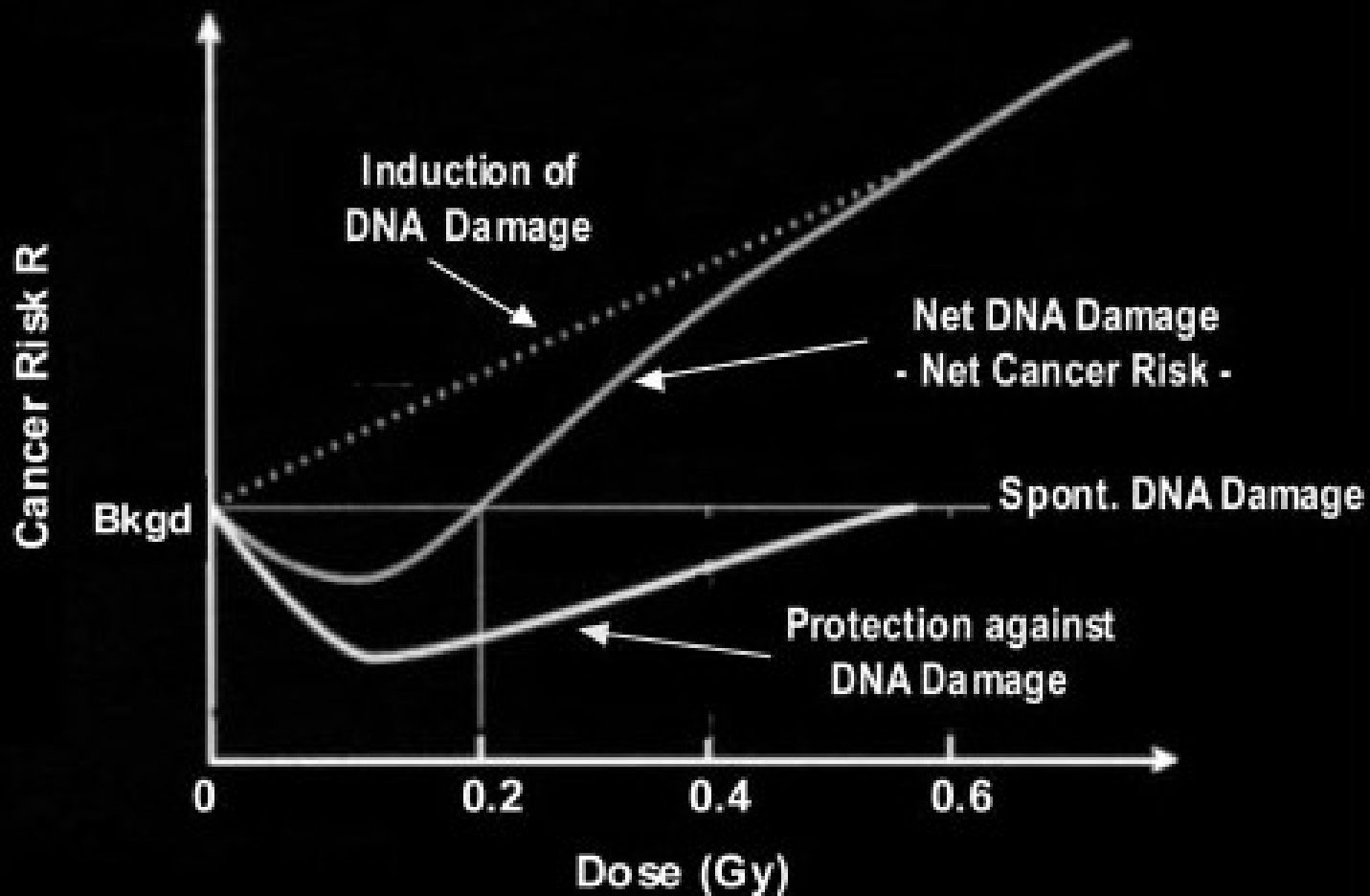
Biological System Response



A Realistic Dose-Response Model



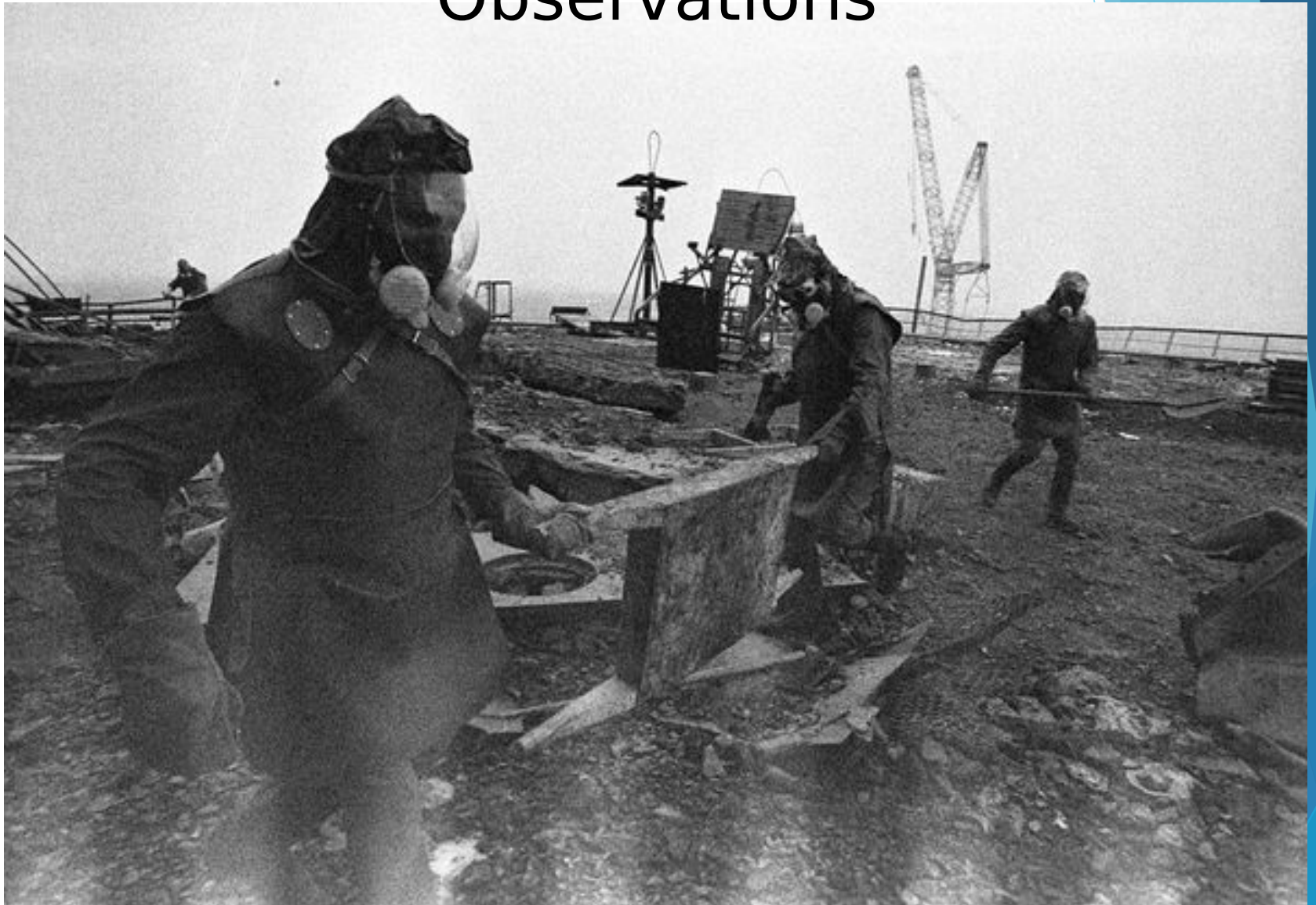
Dual Effect of Low Dose Ionizing Radiation



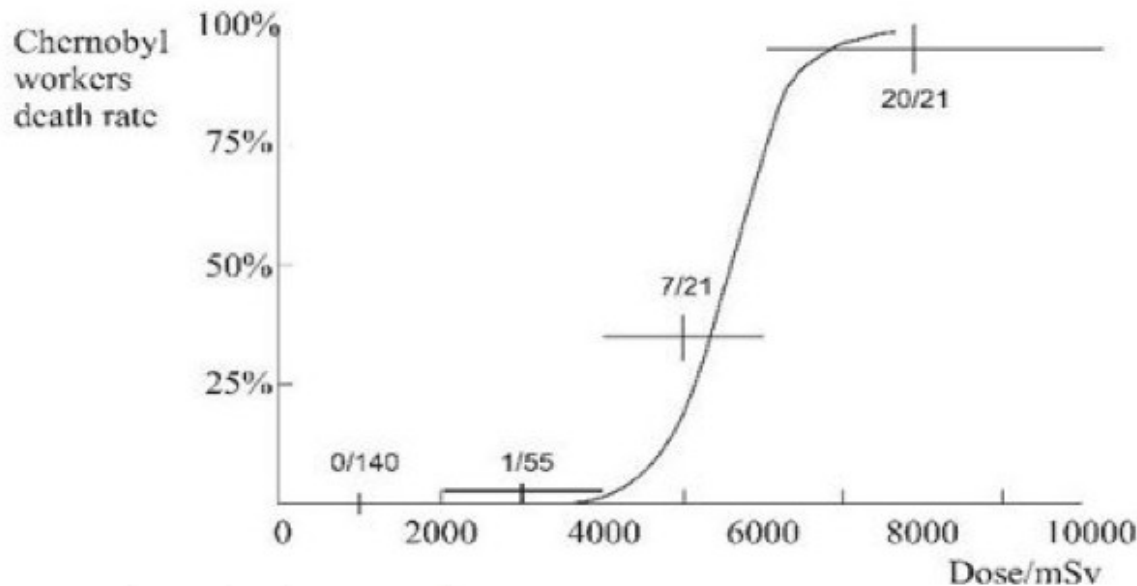
Ref. *Evidence for Beneficial Low Level Radiation Effects and Radiation Hormesis*,
L.E. Feinendegen, MD, The British Journal of Radiology, 78 (2005),
pp. 3-7

Evidence for Adverse Radiation Health Effect Threshold

Chernobyl Radiation Exposure Observations



Chernobyl Emergency Worker Death from Acute Radiation Syndrome



Above 4,000 mSv (400 rem) 27 of 42 exposed workers died.

Below 2,000 mSv (200 rem) none of 140 exposed workers died.

Source: Wade Allison, Radiation and Reason

Chernobyl Radiation Risk

Low radiation doses from Chernobyl dust estimated and compared with natural doses by UNSCEAR⁵

- ▶ In first year following accident, average individual dose received by Northern Hemisphere inhabitants estimated to be 0.045 mSv --- less than 2% of average global annual natural dose
- ▶ Average annual dose from accident received by approximately 5 million people living in contaminated regions only about 1/3 of average natural radiation dose for those regions⁶ (i.e., total dose $\approx$ 133% of natural radiation dose)
- ▶ These doses insignificant in comparison with natural radiation doses in some parts of the world^{7,8}

Chernobyl Radiation Risk (cont.)

Conflict between LNT risk calculations and observed cancer mortalities⁹

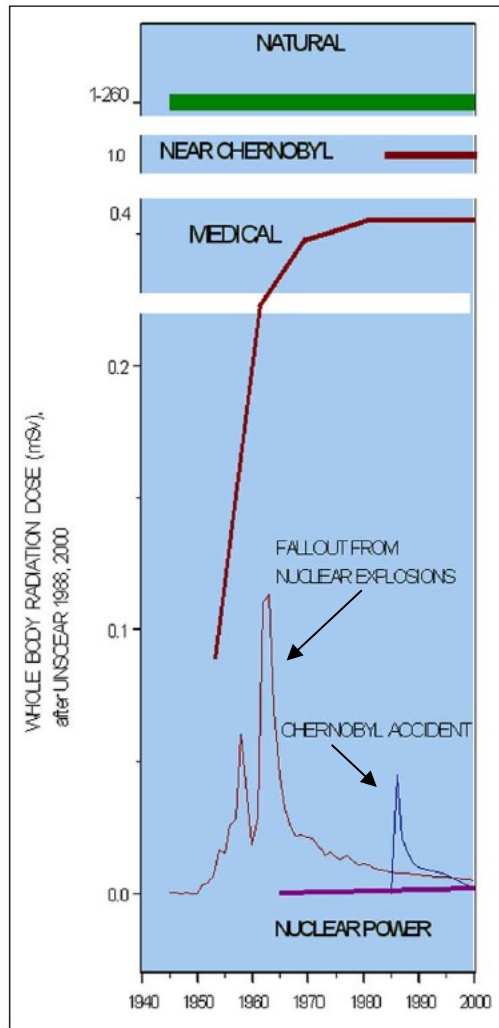
- ▶ UN Chernobyl Forum, using LNT model, predicted 1760 excess cancer deaths for surrounding population of 405,000 (even exceeded excess cancer deaths predicted by ICRP 60 LNT model)
- ▶ **Regardless, no radiation-induced increase in cancer mortality occurred**
- ▶ 4000 cases of thyroid cancer identified in enhanced screening begun immediately after accident; only nine cases resulted in death

Chernobyl Radiation Risk (cont.)

Conflict between LNT risk calculations and observed cancer mortalities (cont.)

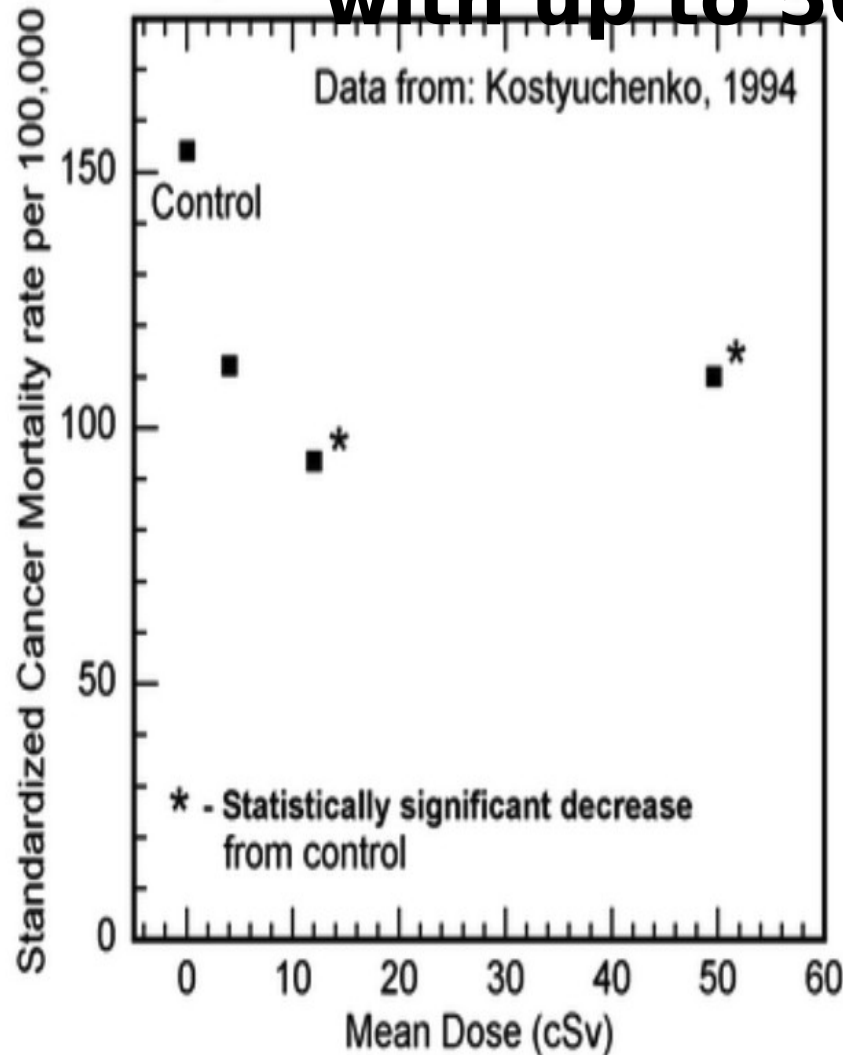
- ▶ Collective dose concept used to predict that 53,000 people in Northern Hemisphere would die of Chernobyl-induced cancer over 50 years¹⁰ – fictitious number that can never be validated
- ▶ Except for thyroid cancers in population of highly contaminated areas of Belarus, Russia, and Ukraine, **no increase in incidence of solid tumors and leukemia, and no increase in genetic diseases observed**^{7,11,12,15}

Worldwide (and Local) Average Annual Radiation Doses from Natural and Man-made Sources



Exposures (in mSv) of global population from radiation sources, and of inhabitants of regions contaminated by radioactive fallout after Chernobyl accident (after UNSCEAR, 1988; UNSCEAR, 2000)

1957 Mayak Weapons Plant Contamination Exposed 7854 People with up to 50 cSv

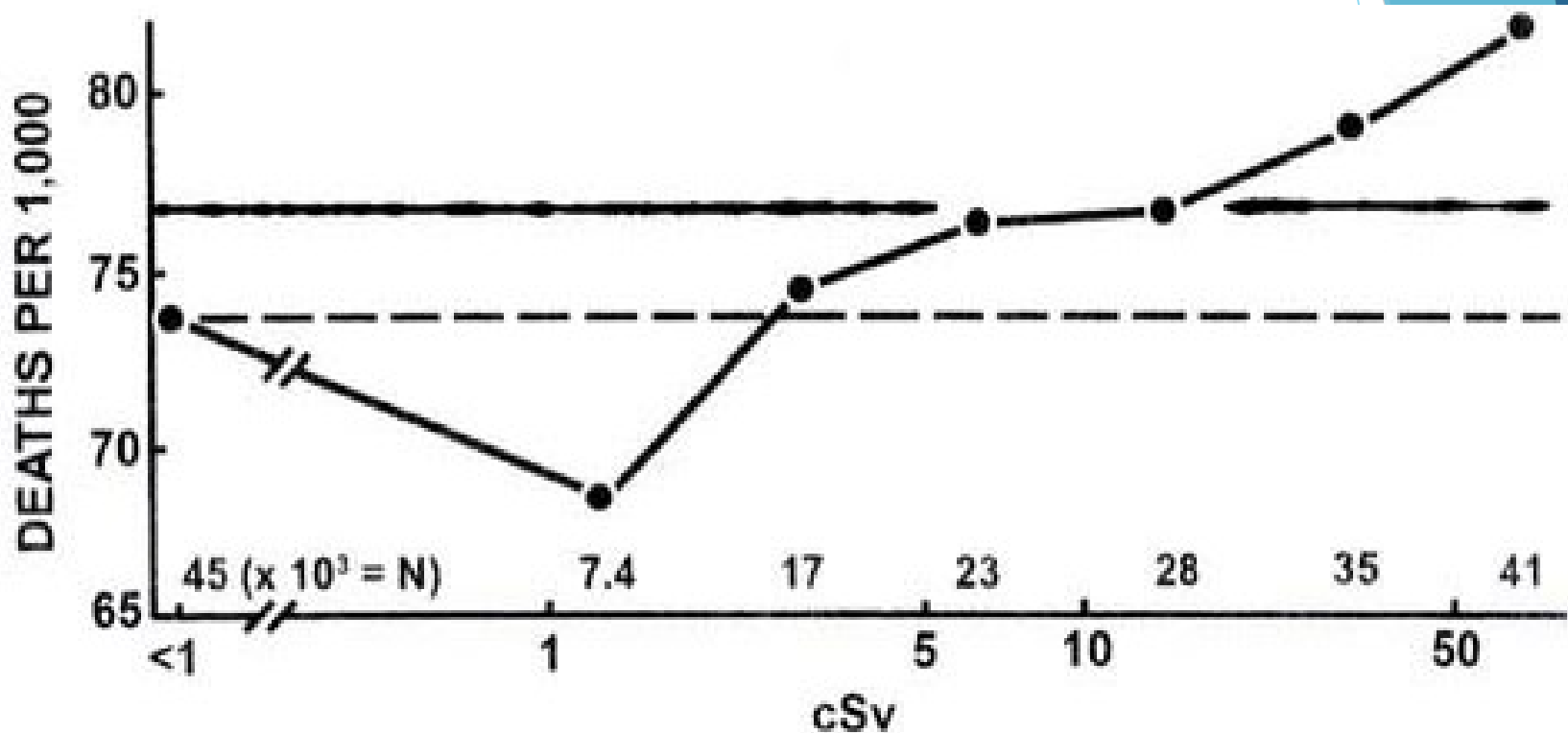


Significantly reduced cancer mortality rates in the 12 cSv and 50 cSv cohorts in villages near the Mayak nuclear weapons facility compared to control cohort

Atomic Bomb Survivors

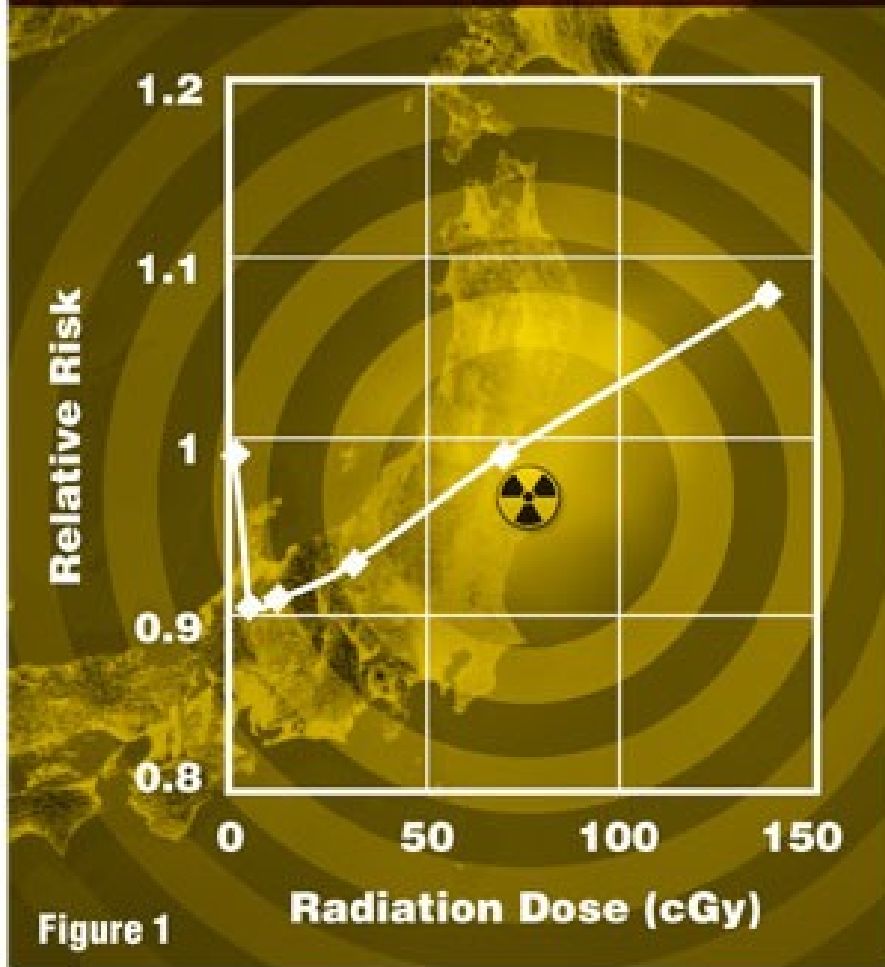


Atom Bomb Survivor Cancer Mortality Rate⁴



(Numbers above abscissa indicate thousands of people included in each point; i.e. the number receiving a dose $\leq x$. **Dashed and solid horizontal lines represent mortality rates for “in-the-city” and “out-of-city” control populations, respectively.**)

Death Rates of A-Bomb Survivors in Hiroshima and Nagasaki (1950-85)



Japanese who were exposed to A-Bomb radiation are outliving their unexposed peers.

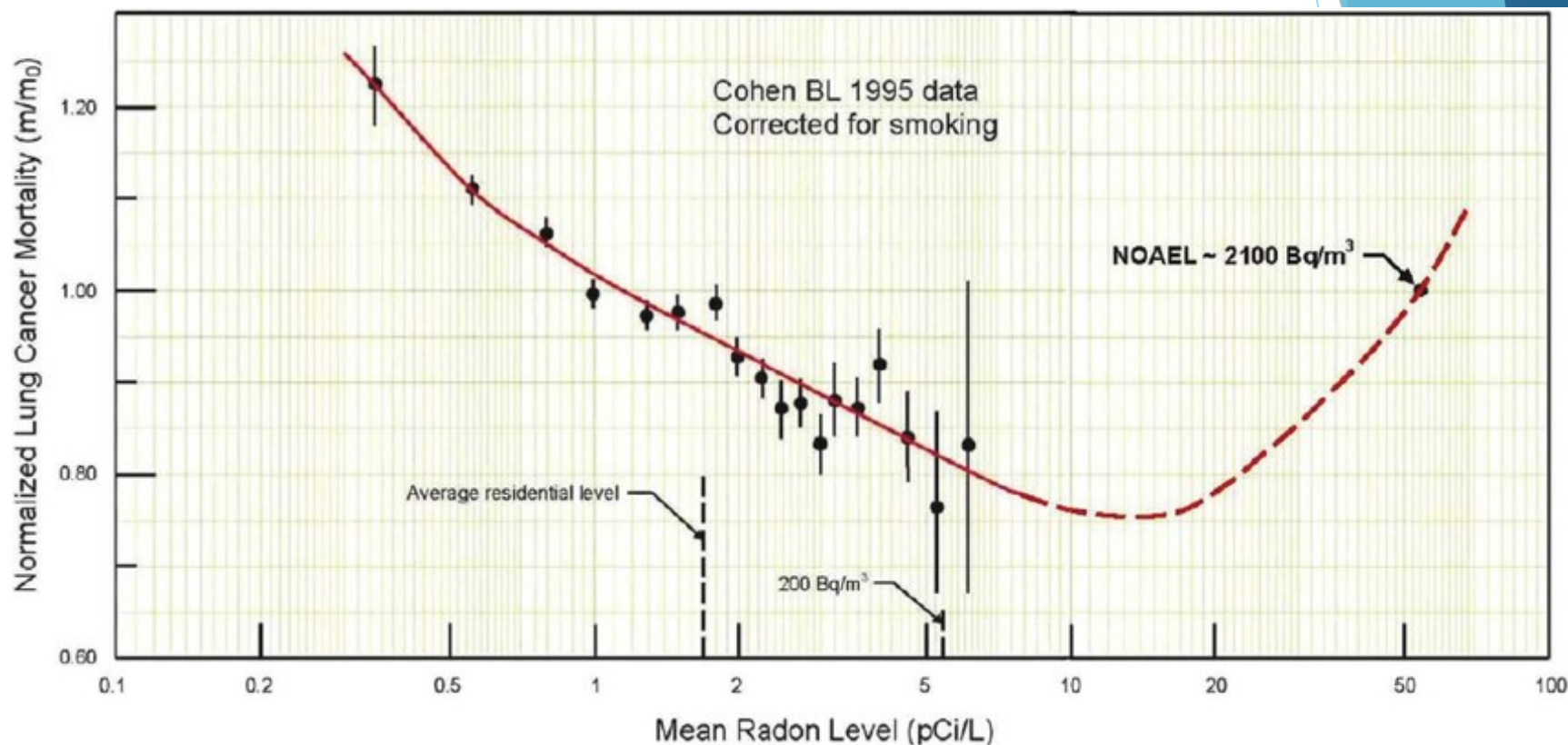
Source: M. Mine et al., *Apparently Beneficial Effect of Low to Intermediate Doses of A-Bomb Radiation on Human Lifespan*, International Journal of Radiological Biology, 58:1035, 1990

Atom Bomb Survivor Average Lifespan

Japan's Mainichi news web site reported on June 30, 2015 that average life span of atom bomb survivors (as of end of March 2015) not significantly different than average lifespan of unexposed populations

- ▶ Average age (population): Hiroshima City, 79.6 (58,933); Hiroshima Prefecture, 82.1 (24,434); Nagasaki City, 79.12 (34,198); and Nagasaki Prefecture, 80.68 (13,669)

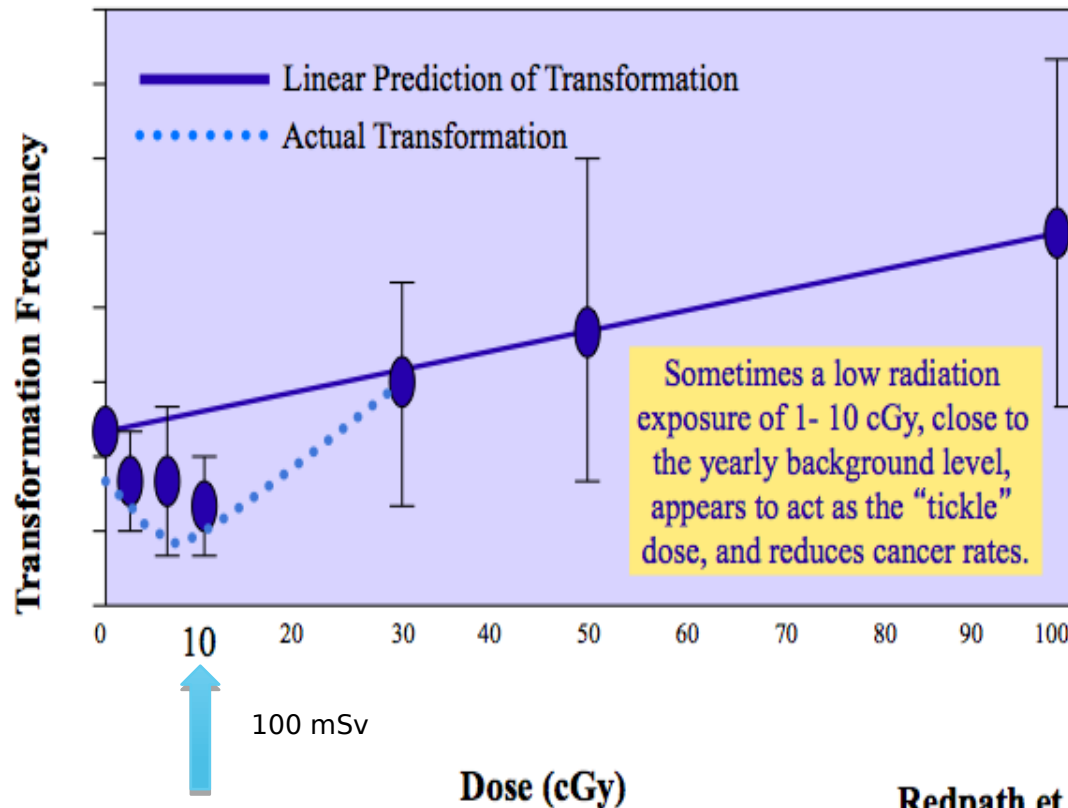
The Truth About Home Radon



NOEAL - no observed adverse effect level

US Low-dose Radiation Studies Disproving LNT Defunded

At very low doses, the transformation frequency is below that predicted by linear extrapolation



Redpath et al. 2001

Radiation Risk Summary

- ▶ Natural ionizing radiation risk from solar radiation doesn't evoke great fear, yet results in thousands of deaths each year in U.S.
- ▶ Nuclear radiation is weaker carcinogen than perceived by most people
- ▶ Studies of populations chronically exposed to elevated natural background radiation (low-level radiation) have not shown consistent or conclusive evidence of associated increases in cancer risk

Radiation Risk Summary (cont.)

- ▶ LNT dose-response model birthed concept of “collective dose” – fraudulent indicator that bears no relation to onset or likelihood of health effects or cancer
- ▶ LNT model low-dose fatality risk calculations in conflict with observed cancer mortality data for Chernobyl accident and for Japanese atomic bomb survivors
- ▶ LNT model ignores body's adaptive protection mechanisms and incorrectly assumes radiation-induced damage is cumulative

Radiation Risk Summary (cont.)

- ▶ Risk of genetic anomaly from 1 rem (0.01 Sv) of radiation exposure to reproductive organs approximately 50 to 1,000 times less than risk of various spontaneous genetic anomalies¹⁴
- ▶ Risk estimate for radiation-induced cancers small compared to normal incidence of about 1 in 4 chances of developing any type of cancer¹⁴
 - Radiotherapy cause of second malignancy in only 1% of patients treated for primary malignancy
- ▶ LNT model overestimates cancer risk from low-dose radiation exposure

References

1. *RISK: A Practical Guide for Deciding What's Really Safe and What's Really Dangerous in the World Around You*, David Ropeik, et al, Harvard Center for Risk Analysis
2. *Outlook on BRC*, Nucleonics Week, September 26, 1991 [BRC = below regulatory concern]
3. *Health Effects of Exposure to Low Levels of Ionizing Radiation: BEIR V*, Committee on the Biological Effects of Ionizing Radiation (BEIR V), National Research Council; ISBN: 0-309-58970-3 (1990)*
4. T.D. Luckey, *Biological Effects of Ionizing Radiation: A Perspective for Japan*, Jour. of Amer. Phys. and Surg., Vol. 16 No. 2, Summer 2011
5. *Sources and Effects of Ionizing Radiation*, United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR 2000; Report to the General Assembly
6. *Observations on the Chernobyl Disaster and LNT*, Zbigniew Jaworowski, 2010
7. *Sources and Effects of Ionizing Radiation*, United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR 2000; Report to the General Assembly, Annex J: Exposures and Effects of the Chernobyl Accident, pp. 451-566

* According to BEIR V (p. 6 and p. 162), the risk of cancer death is 0.08% per rem for doses received rapidly

(acute) and might be 2-4 times less than that (0.04% per rem) for doses received over a long period of time

References (cont.)

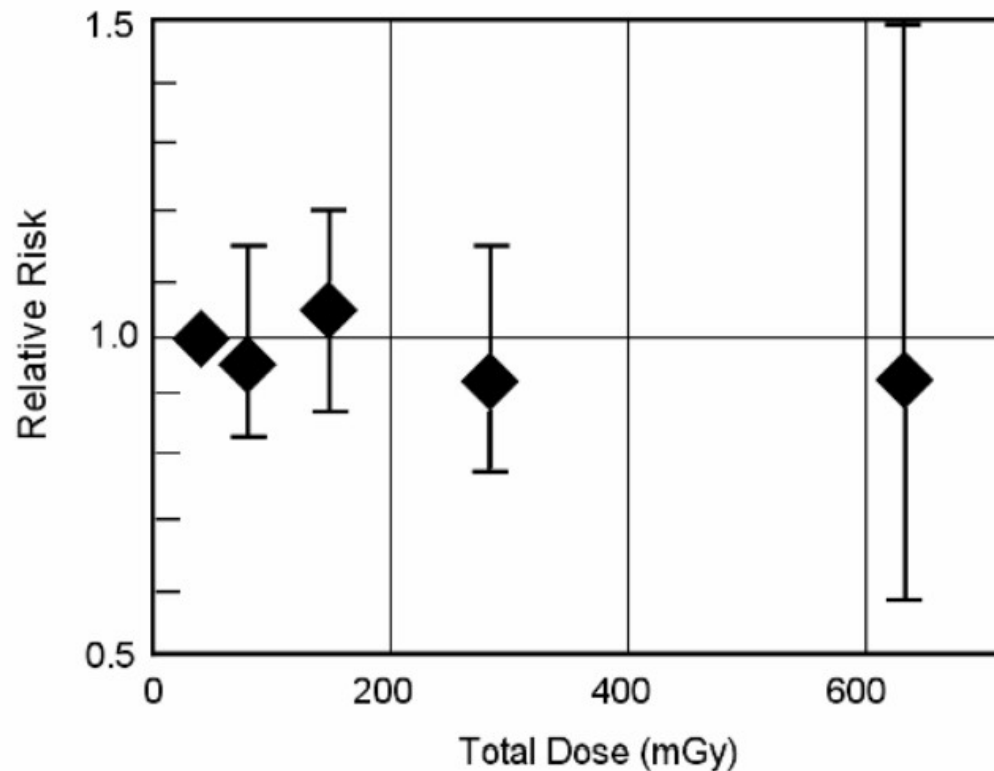
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Supplemental Slides

UN Chernobyl Forum

- Chernobyl Forum (2005) estimated 134 cases of acute radiation syndrome, of which 31 fatalities occurred soon after the accident
- Among 103 survivors, 19 died prior to 2004 from disorders such as lung gangrene, coronary heart disease, tuberculosis, liver cirrhosis, fat embolism and other conditions that are unlikely radiation-induced
- Nevertheless, these deaths presented as

Relative Risk of All Cancer Excluding Leukemia by Cumulative Dose to High Background Radiation in Kerala



Nair et al. *Health Physics*, 2009;
Boice et al. *Radiation Research* 2010

Stressors That Produce DNA-Damaging ROS

